PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Multi-Spindle Threaded Pump

We, SIGMA LUTIN, NARODNI PODNIK, a Czechoslovak Corporation of Lutin Czechoslovakia do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be particularly described in and by the following statement:—

In the pumping or feeding of liquids containing suspensions of granular, fibrous or other solid particles at high pressures, difficulties occur in known types of centrifugal reciprocating piston or other known types of pumps referred to below, because of clogging and damage of the pumps as well as damage to the material conveyed. The problem therefore arises, all over the world, of designing a pump by which thick suspensions can be conveyed in the pressure reactors used in the chemical and allied industries.

This important problem, which constitutes an impediment to more rapid development of the chemico-technological processes for high performances, has during recent years been the subject of intensive research and development the world over. In this connection, a large number of pumps, which in some cases serve as dosers of the most widely varying types have been designed, such as a rotary sliding vane pump, a screw pump, a rotary slide valve pump (doser), and reciprocating piston pumps. Each type, however, suffers from numerous drawbacks due to its construction. By "doser" we mean the kind of pump which delivers in successive doses instead of continuously as in a screw pump. Examples are as follows:

1. Single spindle pumps of the screw-type are subject to the drawback that the solid constituents of the material conveyed are compressed, drastically ground and mechanically damaged, because with a single spindle worm the plug formed has to be firm enough to prevent the pressure from escaping from the reactor. The substance produced, thus loses its physical properties. If the pressure is moderate and the humidity of the material conveyed is uneven, the material is blown out of the single spindle worm. Pumps of this kind, therefore, are only suitable in applications in which mechanical damage to the substance conveyed has no effect on the quality of the product.
2. Dosers of the type having a rotary slide-valve eliminate the aforementioned drawbacks but are subject to other disadvantages, such as the fact that during closing of the chambers the material conveyed is cut by the edges of the slide-valve. A further drawback resides in the fact that after every filling period the entire contents of the doser expand due to the pressure chamber of the reactor into a pressureless container, resulting in considerable losses of propulsive energy and heat.
3. Dosers of the reciprocating piston type are subject to drawbacks as regards the packing of the piston rings and control devices, which rub against the material conveyed and become coated with broken pieces thereof. The piston rings have to be pressed together again whenever they pass through the filling orifices, so that after the free expansion they will again fit into the groove of the working piston on the return stroke. The piston rings undergo friction and consequently break. In this

process, the material conveyed is cut by the edges of the piston and by the piston rings.

4. A doser of the rotary sliding vane type is subject to the drawback that the solid constituents of the material conveyed are broken and cut on the edges of the rotating vane, thus causing damage to the vanes or material. Furthermore, using this type of pump likewise involves the expansion of the vapour blown out of the empty chambers into the atmosphere, resulting in an increase in the heat consumption.

5. There exists, within the range of multi-spindle threaded pumps, a pump being described in British patent No. 812884 but which does not meet the requirements put on dosers and pumps of the type described as described further on, in the text.

Owing to these defects the types of pump or doser described are not reliable in operation and are not sufficiently universal in application to enable them to be used for filling thick suspensions into the pressure reactor from above or below.

The multi-spindle threaded pump shown in Figures 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 of the accompanying drawings enables the above disadvantages to be eliminated by a pump in which the material conveyed consisting of a liquid containing suspended solid particles is conveyed from the atmospheric pressure into the high pressure chamber of the reactor in closed chambers which are formed by the mutual engagement of two or more threaded spindles, mounted askew in respect of one another, having equal thread pitches on their surfaces and rotating in the same direction. The solid constituents, enclosed in these separate chambers, are thrust together with the liquid in the direction of the high pressure, in which process they undergo no drastic or harmful mechanical grinding, breaking, compression or other damage. The capacity of the multi-spindle threaded pump can be easily regulated by altering the speed of rotation and by varying the density on the suspension and is not subject to any upper limit, as with the other types of pump or doser. This pump contains no harmful accelerating mechanisms which operate periodically or which have harmful effects. Its applicability is universal, it can be used for conveying, pumping or dosing any desired liquid, liquids containing solid particles and possibly liquids containing gas suspended therein, from a low pressure to a high pressure and vice versa. By comparison with the known multi-spindle threaded pumps for viscous liquids in which the threaded spindles rotate in opposite directions and are provided with threads of opposite hand the threaded pump proposed offers the advantage that the threaded spindles 21 and 22 rotate synchronously about their own axes 31 and 32, which are set askew in relation to each. This prevents the solid constituents of the suspension from being drawn in between the threads 24 and 25 on the threaded spindles 21 and 22, so that the solid constituents are not ground and damaged, as would be the case with the usual type of multi-spindle threaded pump, of which the use for this purpose is precluded. By comparison with a known pump according to British Patent No. 812884, the technical success obtained and advance provided in the now proposed multi-spindle threaded pump reside in the following characteristic features.

According to the present invention there is provided a multi-spindle threaded pump including two or more rotary threaded spindles which are mounted askew in relation to one another, engage with one another and are provided with equal pitch threads rotating in the same sense, wherein the top edges of the threads of both the threaded spindles intersect with each other, without clearance, on the intersection lines or curves of the top surfaces of the threaded spindles, and said top edges of the threads during rotation of the threaded spindles, within the range of their mutual engagement between these intersection lines or curves, define the flanks of threads which constitute enveloping surfaces for the paths of individual points of generated threads, whilst the top surface of one threaded spindle is defining the bottom surface of the thread of the other threaded spindle and vice versa.

The multi-spindle threaded pump according to the invention operates on the following principles:

The suspension of solid constituents in a liquid or in gas of which the composition depends on the technological process, is conveyed at moderate hydrostatic pressure to the inlet chamber 42 of the case 23, as shown in Figures 1, 2 and 3. From here, the suspension flows, or is conveyed by known types of conveyor worm, to the beginning of the threads 24 and 25 of the threaded rotary spindles. The pump can also operate in the converse direction.

As soon as the first thread of one threaded spindle has engaged the first thread of the other threaded spindle, a threaded chamber therebetween is closed and its contents are thrust, as the threaded spindles continue to rotate, in the direction of the pressure connection 28, where the contents of the chamber are forced outwards by the threads of the threaded spindles.

The tops of the threads of the threaded spindles 21 and 22 take the form of rotating hyperboloids, which can be replaced by other rotating surfaces, if less exacting demands are made on the accuracy and performance of the pumps, or if they are re-

quired for technological reasons. In the narrow zone around the neck plane the hyperboloid threaded spindles can be replaced by cylindrical spindles on shafts set askew in relation to each other, and in the wider zone of the neck plane an osculating torus can be used for generating the top edges of the threads. If use is to be made, for the construction of the threaded spindle, of a section of the hyperboloid which is situated at a distance from the neck plane, the hyperboloid can be replaced by a rotation cone. The shape of the top of the threads of the threaded spindles, however, can also be formed by a combination of the aforementioned geometrical shapes, and if necessary, any rotary surface can be used for the construction of the top of the threads, the form of the surface used being as close as possible to a certain hyperboloid, so that all the mathematical expressions and considerations given hereinafter apply to systems of rotary hyperboloids with intersection in straight lines; as a general principle, however, they also apply to the aforementioned shapes of the top surfaces and their combinations, as the basic principles for the construction of the threads, and of their flanks, discussed in detail hereinafter, are generally valid; in their simplest form, and strictly speaking, they nevertheless only apply to rotary hyperboloids with intersection in straight lines.

Whether it is possible to dispense with the rotary hyperboloids and to replace them by some other form will depend on the operational and constructional requirements of the pump.

As may be seen from the above description, the gaps between the threads on one spindle are closed by the threads of the other threaded spindle. In order to ensure that in the range of engagement, which is limited by the intersection lines or intersection curves of the top surfaces of the threaded structures, the thread will provide, in the gap on the other spindle, as far as possible a hermetic sealing effect, the system of top thread spirals must be selected in such a way that these thread spirals intersect without any clearance on the intersection lines or general intersection curves. This will ensure, contact between the edges of the top threads, without any clearance, in the boundary points of the range of engagement. If this condition is not fulfilled, free wedge-shaped intermediate cavities will occur between the top edges of the threaded spindles, enabling the material conveyed to pass from the space between the threads and having a higher pressure into the space between the threads having a lower pressure, so that both the efficiency of the conveying operation and also that of the pressure are considerably reduced.

It was found in a geometrical and mathematical investigation that a system of equal threads having the property described, can be carried out on all rotational bodies, and that the fulfilment of the aforementioned condition depends on the magnitude of the pitch of these thread spirals and possibly on the course taken by the pitch, as long as the top surfaces of the threaded spindles intersect in curves which have the shape of the top thread surfaces and are at a shorter distance from the shafts mounted askew, about which the threaded spindles rotate. In the event of rotary hyperboloids which intersect in straight lines, the pitch s is expressed by the equation:

$$s = \frac{180°}{\beta} \cdot \frac{a \cdot \sin\alpha \cdot \sin\beta}{\cos\alpha\eta}$$

In the above:

β=half the angle of the intersection straight lines (angular distance);

α=the angle enclosed by the axes of the threaded spindles;

$\alpha\eta$=the angle of inclination of the straight lines generating the hyperboloid top thread surfaces.

It was found that the intersection of two rotation hyperboloids was governed by the equation:

$$\cos\beta = \frac{b^2 \cdot u}{a\,(a^2+b^2+\sqrt{(a^2+b^2)^2-b^2 \cdot u^2}}$$

It was also found that:

$$\sin\alpha = \frac{b \cdot u}{a^2+b^2}$$

In the above:

u=the length of the shortest transversal line between the rotation axes, mounted askew, of the threaded spindles;

a=the radius of the semi-circle of the top hyperboloid body;

$$b = \frac{a}{\tan\alpha\eta}$$

If the threaded bodies are of the type in which the top threaded surfaces do not represent hyperboloids with intersection in straight lines, the equation for the pitch s is altered to the following:

$$s = \frac{180°}{\beta_0} \cdot \frac{a \cdot \sin\alpha \cdot \sin\beta_0}{\cos\alpha_t}$$

In the above:

α_t=The inclination of the tangents at the points of the intersection curve, in respect of the rotation axis;

β_o=half the momentary angular distance between the two terminal points of the top thread, in the range of engagement.

The equation given can be used provided that the intersection lines or curves 43 (Figure 10) of the top surfaces of the threaded spindles 21 and 22 are coincident in shape and spationally symmetrically orientated with respect to the central axis of an imaginary central rotation body 44. This means that both intersection lines or curves are the generating curves or lines of the imaginary central rotation body 44 the central axis 45 of which represents the spatial symmetry axis of skew axes of rotation 31 and 32 of the threaded spindles 21 and 22.

In this case the axis 45 of the said skew rotation axes 31 and 32 on the threaded spindles is at the same time the axis of a further imaginary central rotational hyperboloid 46 of which the straight generating lines are identical with the axes of rotation shafts 31 and 32 of the threaded spindles. If the condition of the existence of this further central rotation body is fulfilled, this guarantees, for the system of threaded spindles, a spatial symmetry which, from a geometrical point of view, enables use to be made, in solving this problem, of all the knowledge gathered mathematically for rotary hyperboloids with intersection in straight lines and also for rotary bodies with intersection in curves.

From the equation last given, for the thread pitch on the top surfaces of the threaded spindles in the general form, i.e. with intersection in curves, it can be seen that the pitch of the thread is variable along the intersection curves. The variability of the pitch is due to the fact that the magnitudes β_o and α_t undergo no linear change along the intersection curves. The thread pitch thus has to be investigated separately for each longitudinal element. Alternately, a constant thread pitch on the intersection curves is obtained by establishing a certain relationship between the magnitudes β_o α_t.

All the mathematical expressions fix a system for the top thread spirals of threaded spindles on shafts mounted askew, in which the individual threaded spindles intersect on the straight lines or curves of intersection, without any intermediate clearance, thus fulfilling the first condition for an optimum sealing effect.

The equations indicated can likewise be applied without difficulty to rotary bodies taking some other form than hyperboloids with intersection in straight lines, particularly in the case of cylinders or cones of which the shape borders on that of a rotation hyperboloid. (A cylinder is a hyperboloid in which the inclination of the generating lines is zero, while a cone is a hyperboloid of which the "neck circle has a diameter of zero, and represents a so-called asymptotic cone). Neither is there any difficulty in applying the aforementioned equations to osculating toruses, by which the rotation hyperboloid can be replaced in the wide zone around the neck plane.

The thread flanks, of which the shape is just as important for a satisfactory sealing of the intermediate spaces between the threads, were investigated as surrounding surfaces of the paths taken by the individual points of the top edges of the threads during the rotation of the threaded spindles. To define the form taken by the flanks of the threads is a very complex mathematical problem. It has nevertheless been proved in theory and confirmed in practice that in the range of engagement the following course is taken by the sealing of the threads in threaded spindles having a top surface of rotation hyperboloids which intersect in straight lines:

1. If the tooth flanks are produced by a hobbing process in which the tooth flank is formed by one single hobbing operation with the top spiral of the tool inserted to a sufficient depth to reach the foot of the thread of the spindle, then the tooth flank of one spindle is contacted, without clearance, by the top flank of the other spindle, in one half of the range of engagement, i.e. starting from that part on the intersection line at which the top thread spirals of the spindles intersect, as far as the point of contact between the relevant top thread spiral of one spindle with the bottom of the thread of the other spindle. In the remainder of the range of engagements the top edge moves gradually away from the tooth flank, in about three-quarters of the range of engagement the distance between the top edge of the threads and the relevant tooth flank is at its maximum after which it decreases, once again becoming zero at the terminal point of the range of engagement.

2. If the tooth flanks are produced by a hobbing process which is based on a constant angle between the axes and in which the hobbing tool is steadily inserted into the depth of the foot of the threading of the threaded spindle, then in the range of intersection of the top surfaces of the threaded spindles a wedge-shaped intermediate cavity will be formed (the top edges of the threads intersecting with a certain amount of clearance), and the contact between the tooth flanks commences in the zone underneath the top surface of the threaded spindle, in the direction towards the axis of rotation; the further course taken by the engagement is similar to that described under 1.

Owing to the fact that the top edge of the thread, in part of the range of engagement, has moved away from the relevant tooth flank, the non-hermetic intermediate

space is lenticular in shape (Figure 4). The size of the non-hermetic gap (the maximum distance between the top edge and the tooth flank) is directly proportional to the angle α which is enclosed by the rotation axes of the threaded spindles, to the inclination of the angle α_n of the top generating curve of the hyperboloid with respect to its axis of rotation; and this size is indirectly proportional to the value "U", i.e. to the shortest transversal line between the skew rotation axis of the threaded spindles. A further top thread spindle which, in the direction of the rotation of the axis is staggered in relation to the first by one half of the pitch, and which forms the second top edge of the gap between the threads, lacks hermeticity in the first part of the range of engagement; in the second part of the said range it contacts the tooth flank and is sealed by this latter. In this manner, the lenticular non-hermetic intermediate spaces alternate over the individual thread flanks (being diametrically opposite to one another in respect of the centre of the range of engagement). In the system of threaded spindles the aforementioned non-hermetic spaces generate a very complicated cataract with a high hydraulic resistance. Through this cataract part of the liquid of the material conveyed flows back in the direction of the higher to the lower pressure, the quantity of liquid flowing back being governed by the magnitude of the compression ratio between the threaded spindles, i.e. by the difference between the contents of the first threaded chamber at the inlet and the contents of the last threaded chamber at the outlet. Since it is necessary, however, for a certain quantity of the liquid to be conveyed back into the suction chamber during the rotation of the threaded spindles, of which the thread content is not constant over their entire length, these non-hermetic spaces are necessary. As a rule, the amount of non-hermeticity is not sufficient to detract from the high volumetric efficiency of the threaded spindles.

The production methods described below in greater detail are based on principles enabling the tooth flanks to be produced in the manner described by the geometrical solution. These production methods are of a simple nature and can be carried out by the usual processing machines. The principles of these methods could also be applied with the manufacturing of such threaded spindles the thread surface of which keeps the shape or any rotary body with the intersection curves according to the principles being already described.

In practice, the threaded spindles can be used in either as expanders or pumps. It has been proved by practical tests that when they are used as expanders it is more advantageous for the suspension to be conveyed in the direction from the narrower to the wider end of the pump, so that the inlet threads are those for which the threaded chambers have the minimum content, while the outlet threads are those corresponding to the maximum content of the threaded chambers. In the converse operation, more energy is consumed for the same expander performance, so that the efficiency of the expander becomes less satisfactory. When the threaded spindles are used as a pump, the more favourable method of operation is the opposite to that adopted in the case of an expander.

The volumetric performance of the threaded spindle is expressed by the equation

$$Q = i \cdot v_v \cdot k \cdot n \cdot \eta$$

In the above:

k=coefficient, in which account is taken of the hydraulic conditions in the threaded spindles, on the entry and on the emergence of the substance;

η=volumetric efficiency of the pump;

v_v=the volume of the last chamber of the threaded spindle, in cubic metres;

i=number of threaded spindles;

n=speed of rotation of the threaded spindles, in r.p.m.

The required performance is calculated as with the other volumetric pumps.

The final pressure reached is dependent on the following: the size of the cataract formed by the clearances in the threads; the rotation speed of the pump; the length of the threaded spindles; the density of the substance and the size of this solid constituents therein; the temperature of the substance. The pressures obtained are the higher, the smaller the non-hermetic intermediate spaces forming the cataract (i.e. the smaller the angle of inclination of the generating line of the threaded spindle, this line forming the top of the threads, and the smaller the angle enclosed by the axes of the threaded spindles; the non-hermetic spaces are further reduced by increasing the shortest transversal line between the rotation shafts set askew); the longer the threaded spindles (the number of sealing points in the cataract being correspondingly greater, the higher the speed of rotation, the greater density of the substance conveyed and the smaller the solid constituents present in the substance.

As proved by theoretical investigations and confirmed by practical tests, certain threaded spindles can only be used for conveying or pumping operations within a certain narrow range of pressures. Figure 8 shows the course taken by the pressure p in a threaded spindle at a point distant l from the throat plane. Point 47 represents the outlet pressure to which the spindle conveys the substance. Point 48 represents the pressure in

the inlet cavity of the spindle, i.e. in the first thread of the spindle. The curves between points 47 and 48 represent the course taken by the pressure at different speeds of rotation. The courses taken by the pressure under the equal pressure line 49—47 may be regarded as economically acceptable.

Figure 9 shows the course taken by the pressure *P*, as a function of the rotation n of the spindles. The graph shows that for any given type of spindle there is only one rotation speed η_o which corresponds to a given pressure and with which the quantity conveyed, Q, is equal to zero. This rotation speed is termed "zero rotation speed, η_o". The threaded spindles will only operate as pumps in the case of rotation speeds which are greater than the "zero rotation speeds".

The graphs given are characteristic of a multi-spindle threaded pump and can be determined either by tests on prototypes or by theoretical investigations, which are nevertheless very difficult.

The complicated cataract between the threads, which has already been described, only gives passage to the liquid of the material conveyed, and the solids cannot find their way through the clearances, because in these positions the suspensions are thickened to such an extent that "a plug" forms. In the zero speed of rotation the quantity conveyed is equal to zero, and at low rotation speeds the liquid phase flows through the non-hermetic clearances, from the range of the highest pressure into the lower pressure into the inlet of the pump. The solids do not pass through these clearances. This is a favourable property of the pump of this type, since in the event of a failure in the pump or its "drive" (e.g. a failure in the power supply) no special shut-off devices are required for the purpose of immediately sealing off the pressure chamber from the pump.

The multi-spindle threaded pumps are also intended for discharging suspensions from pressure reactors or other pressure chambers into a chamber with a lower pressure or into the atmosphere. This application is important in cases in which the discharge operation is not accompanied by any violent expansion, as in the case of the discharge of a suspension consisting of boiled cellulose and a boiling agent from a boiling apparatus operating continuously. In this application it is sufficient for the threaded spindles to be given a rotation speed of zero.

In view of the hermeticity between the thread and the variability of the volume of the chamber the principle suggested could also be used for the purpose of employing the pump as a pneumatic motor, steam engine or internal combustion engine, with an infinitely variable expansion.

An important characteristic of the multi-spindle threaded pump resides mainly in the fact that the solid constituents of the suspension are not drawn into the wedge-shaped intermediate spaces between the top and the bottom (edges) of the threads engaging one another. It is true that in the mutual engagement of the threads, i.e. of the tops and bottoms, there are small differences between the peripheral speeds but these do not cause the solid constituents to be drawn in but result, on the contrary, in their extraction from the wedge-shaped intermediate cavities; this means that these latter are not obstructed or jammed between the threads. This has been determined by theoretical investigation and also confirmed by practical tests. In these investigations it was found that even when shavings were violently forced into the intermediate cavity between the threads they were flung out of this wedge-shaped cavity.

Production of Threaded Spindles

1. By the hobbing process, as shown in Figures 5 and 6, a tool must be prepared having the same shape as the threaded spindles and provided with cutting edges. The flanks of the tool must be undercut, so that cutting edges are formed (theoretical cutting points), which correspond to the top thread spiral. On the threaded spindle to be machined the thread is first of all pre-cut or pre-turned in depth, as far as the bottom of the thread. After this operation, the hobbing tool, the width of its thread being somewhat narrower than the gap eventually to be produced in the threading, is inserted into the machined threaded spindle, as far as the bottom of the thread. The workpiece and the tool are initially caused to rotate synchronously. In order to bring the top cutting edges of the tool into correct position with respect to the thread edges of the threaded spindle to be machined, there must be added—during their mutual synchronous rotation—an additional rotary movement of the tool, which results in either increasing or decreasing of rotations of the tool. This increase or decrease in rotations must be made gradually and the purpose of this is to cause the top edges of the tool to approach the flank of the tooth of the threaded spindle to be machined. So the synchronisation of the mutual speed is changed only at the time of approaching the tool to the tooth flank. In this manner, the tooth flank is formed by the cutting edges of the tool. This means that the cutting edges of the top cutting spiral of the tool have cut, along the range of engagement, the curved paths required by the engagement as determined geometrically and kinematically. The process is nevertheless subject to the drawback that with a preselected synchronous rotation of the workpiece and tool, and with

a smaller number of cutting edges, only certain curves of the thread flanks of the tool are cut out correctly, these being separated from one another by a distance corresponding to the pitch of the cutting edges of the tool. This operation causes regular and curved grooves to be formed on the flanks of the threading of the spindle. The pitch of these grooves depends on the number of cutting edges in the tool, and they have to be ground off, either by hand or with an emery wheel having the same profile as the tool itself. The system of curves generated by the cutting edges of the tool, however, determines the exact engagement of the surface of the thread flanks 24 and 25 of the threaded spindles 21 and 22.

2. In the other hobbing process the same tool is used as in that described above. The tool, however, is inserted in the machined workpiece at a constant angle ′ between the axes 31 and 32, starting from the contact between the top surfaces of the tool and those of the workpiece and proceeding to the correct depth in the thread on the foot of the threaded spindle. In view of the foregoing, and despite the fact that the synchronization of the speed of the threaded spindle and the tool is not disturbed at any moment during the hobbing process, a corrected and sufficiently smooth thread flank is formed. After the completion of the process of producing a thread flank, the tool is extracted along the same path, and by an axial displacement of the flank along its rotation axis or an axial displacement of the machined threaded spindle the gap between the threads is set to the required width, and the process of producing the other thread flank can be commenced, by the same method. The thread flanks thus produced have a slight inaccuracy on the intersection lines or intersection curves, but the non-hermetic area as a whole is reduced. This process thus provides a corrected tooth flank.

3. A further method of production is that carried out on the lathe, in accordance with Figure 7, the cutting edge of the cutting tool moving over the common intersection line P1 the threaded spindles 21 and 22. The threaded spindle 21 or 22 is inserted in a special device in such a way that it rotates about its own axis 31. After the removal of the first chip along the generating line of the intersection of the hyperboloid of the surface of the threaded spindle 21, the cutting tool returns to its initial position. The threaded spindle 21, as the machined workpiece, is then rotated about the axis 32 of the other hyperboloid of the imaginary spindle 22. A fresh cutting thickness is thus moved into position under the cutting edge of the tool, which moves in accordance with the preselected thread pitch. This process is repeated until the cutting tool has left the range of engagement.

To ensure, however, that the thread flanks 24 on the threaded spindle 21 are turned correctly, the cutting tool, whenever it has been returned to the initial position, and before starting the next cut, must be displaced by a distance corresponding to the element Δs of the pitch, which corresponds to the angular element $\Delta\beta$ of the rotation of the threaded spindle 21 about the axis 32, and this displacement of the tool must take place parallel with the interception line and in the same direction as the thread of the threaded spindle 22 with the rotation axis 32.

As the cutting edge of the tool, strictly speaking, merely replaces a point on the edge of the top thread of the threaded spindle 22, and moves along the same path, as was the case in the intersection of the cutting edges in the top edge of the thread of the hobbing tool, the tooth flank 24 or 25 on the threaded spindle 21 or 22 respectively will be formed, in this case likewise, along the exact intersection line, i.e. in accordance with the characteristic of the contact in the range of engagement without intermediate clearance.

This method of production offers the advantage that one chip after another is removed, so that if the tool has a somewhat rounded cutting edge a completely smooth and cohesive surface is obtained on the thread flanks 24 and 25, without grooves. When the threads are produced in this manner, no limits are set to the diameters of the threaded spindles 21 and 22, and since in the production operation, only one cutting edge of the tool is engaged at any one time, the cutting resistance is comparatively low.

The securing device must be arranged in such a manner that the common intersection line is parallel to the axis of the lathe, i.e. with the movement of the main support, as the cutting edge of the tool must move along the edge of this straight line. The position of the shafts 31 and 32, mounted askew, is governed by the shape of the threaded spindles 21 and 22. Since the rotation axis 31 of the threaded spindle 21, as the machined workpiece is askew in relation to the rotation axis of the spindle of the lathe, the threaded spindle 21 must be driven at a constant angular speed about its own rotation, by means of homokinetic joints. The additional movement of the cutting edge of the tool along the cutting intersection line is obtained by a method in which the cutting edge of the tool, after each rotation of the arm 29 about the axis 32 by the element $\Delta\beta$ of the angle, is displaced by means of a small support along the cutting generating line by a distance corresponding to the element Δs of the pitch. For this purpose accurate scales must be provided on the arm 29 and on the

spindle of the small longitudinal support. This method of production offers the further advantage that the machining of the surface of the hyperboloids and the production of the threads can be carried out with one and the same device.

WHAT WE CLAIM IS:—

1. A multi-spindle threaded pump including two or more rotary threaded spindles which are mounted askew in relation to one another, engage with one another and are provided with equal pitch threads rotating in the same sense, wherein the top edges of the threads of both the threaded spindles intersect with each other without clearance on the intersection lines or curves of the top surfaces of the threaded spindles, and said top edges of the threads during rotation of the threaded spindles, within the range of their mutual engagement between these intersection lines or curves, define the flanks of threads which constitute enveloping surfaces for the paths of individual points of generated threads, whilst the top surface of one threaded spindle is defining the bottom surface of the thread of the other threaded spindle and vice versa.

2. A multi-spindle threaded pump as claimed in claim 1, wherein the top threads on the threaded spindles are of the form of rotary hyperboloids which intersect in straight lines and have a constant pitch on the said straight lines, which is defined by the equation:

$$s = \frac{180^\circ}{\beta} \cdot \frac{a \cdot \sin \alpha \cdot \sin \beta}{\cos \alpha\eta}$$

where

- s = pitch of threaded spindles on intersection lines
- a = radius of the throat plane of the top hyperboloid
- α = angle between axes of rotation of threaded spindles
- $\alpha\eta$ = angle of inclination of generating line of the top hyperboloid

and

- β = half-angle of intersection lines (their angular distance measured in the throat plane),

and wherein the top edges of the threads of the threaded spindles intersect, without clearance, along the entire length of the intersection lines.

3. A multi-spindle threaded pump as claimed in claims 1 and 2 wherein the angle which encloses the rotation axes of the threaded spindles which are of the form of rotary hyperboloids intersecting in straight lines, is defined by the equation:

$$\sin \alpha = \frac{b \cdot u}{a^2 + b^2}$$

where

- α = angle between rotation axes of threaded spindles
- u = shortest diagonal (transversal line) between askew rotation axes in the throat plane of hyperboloids
- a = radius of the throat plane of the top hyperboloid
- b = a tan α, where tan α represents angle of inclination of generating lines of the top hyperboloid

4. A method of manufacturing threaded spindles of the multi-spindle threaded pump as claimed in claims 1—3, wherein the threads of the threaded spindles are first pre-cut or pre-turned to the bottom of the thread and then formed by hobbing the threaded spindles of the machined workpiece which rotates in the same direction, and initially synchronously with the hobbing tool, the latter being constructed such that its cutting edges are situated on the top edges of its thread, the tool flanks being undercut such that the cutting operation is only effected by the tool on the top edges of the thread of the workpiece, the width of the thread of the tool being smaller than the width of the threaded parts of the spindle to be machined, the hobbing of the threaded spindle being carried out such that the hobbing tool at the beginning of the hobbing operation is inserted into the threaded spindle to be machined to a preselected thread depth, the thread flanks then being formed by an increase or decrease in the speed of rotation of the hobbing tool during the cutting process about its axis of rotation in a direction corresponding to the approach of the cutting edges to one or other of the thread flanks.

5. A method of manufacturing threaded spindles of the multi-spindle threaded pump as claimed in claims 1—3, wherein the threads are formed by hobbing by means of synchronous, and in the same direction, rotation of a tool and spindle to be machined, the tool being constructed such that its cutting edges are situated at the top edges of its thread and its thread flanks undercut, and the tool being steadily inserted with a constant angle between the axes of the tool and spindle, into the machine spindle from the moment when the top surfaces of the tool first make contact with the threaded spindle until the preselected thread depth is reached in the threaded spindle.

6. A method of manufacturing threaded spindles of the multi-spindle threaded pump as claimed in claims 1—3, wherein the threads are formed by a turning operation, with the use of a turning tool, the latter being moved along an addendum generating line of the

threaded spindle, which line forms the intersection line of engagement of the threaded spindles, the machined threaded spindle rotating about its own axis of rotation and also being rotated on the planetary principle, after the termination of each cut, about the axis of rotation of the other threaded spindle, with a simultaneous periodic displacement of the turning tool, in the direction of its path of movement, by a distance corresponding to the pitch element Δs, the magnitude of the displacement corresponding to that of the planetary rotation $\Delta\beta$ of the machined threaded spindle about the rotation axis of the other threaded spindle.

7. A multi-spindle threaded pump as claimed in claim 1 to 3, wherein the top thread on the threaded spindles takes the form of toruses, rotatory cones, rotatory cylinders or other rotational bodies, and intersect in curves, having a pitch on these intersection curves which is defined by the equation:

$$s = \frac{180^\circ}{\beta} \cdot \frac{a \cdot \sin\alpha \cdot \sin\beta}{\cos\alpha_t}$$

where

s=pitch of threaded spindles on intersection lines

a=radius of the throat plane of the top hyperboloid

α=angle of axes rotation of threaded spindles

β=half-angle of intersection lines (their angular distance measured in the throat plane)

α_t denotes the angle of inclination of the tangent, at the points on the intersection curve, in respect of the rotation axis, and the angle β is the momentary angle of intersection between the top terminal points of the thread in the range of engagement.

8. A multi-spindle threaded pump as claimed in claim 1 and substantially as described with reference to the accompanying drawings.

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1140577 COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

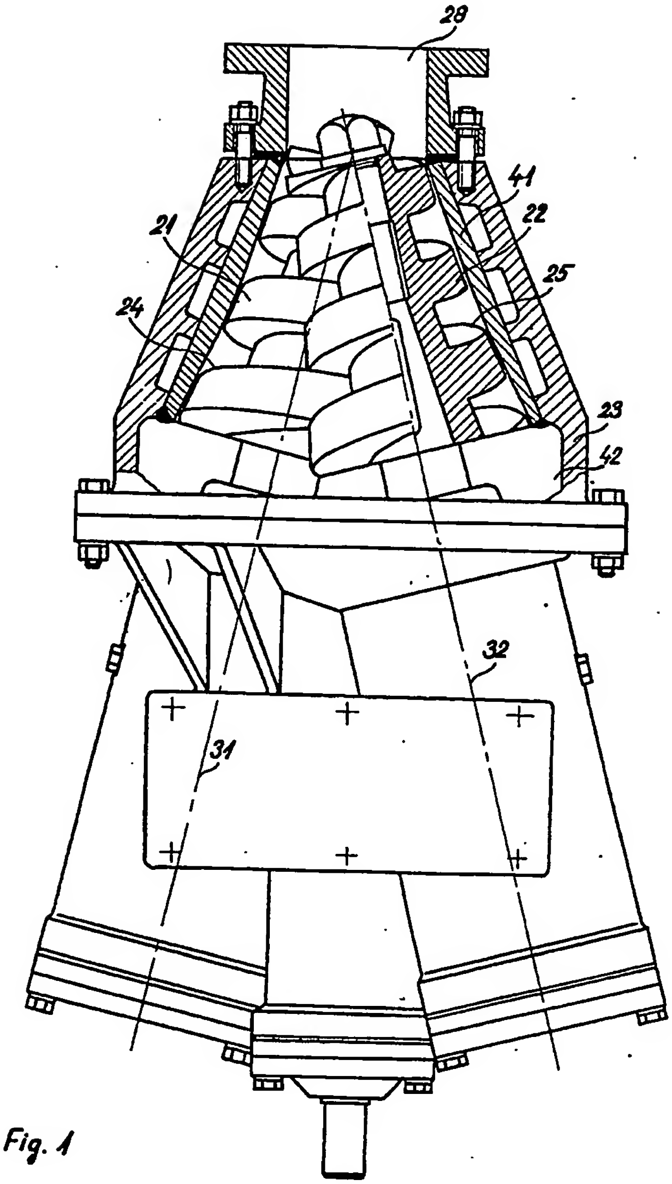


Fig. 1

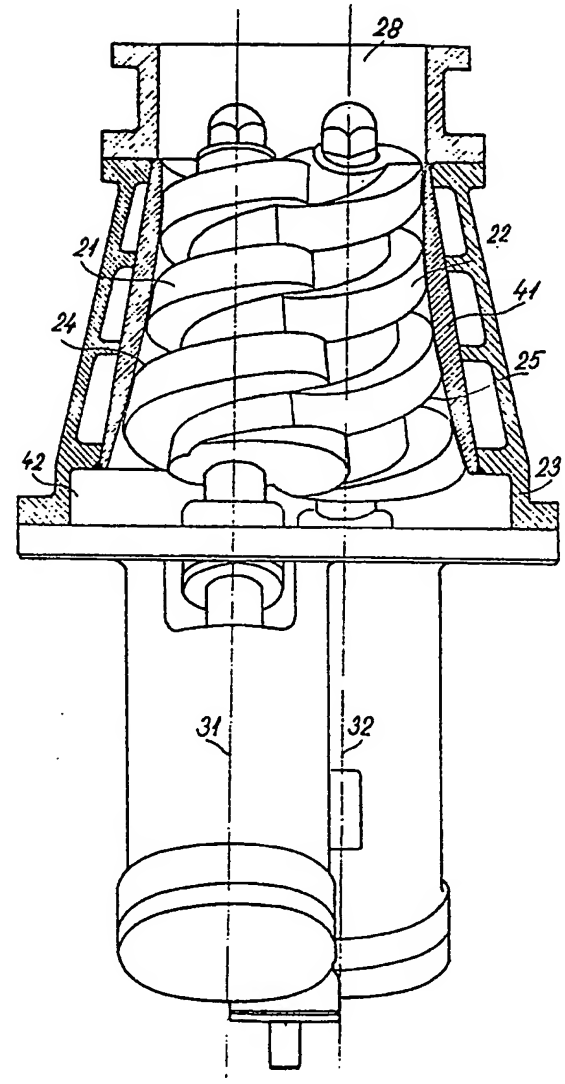
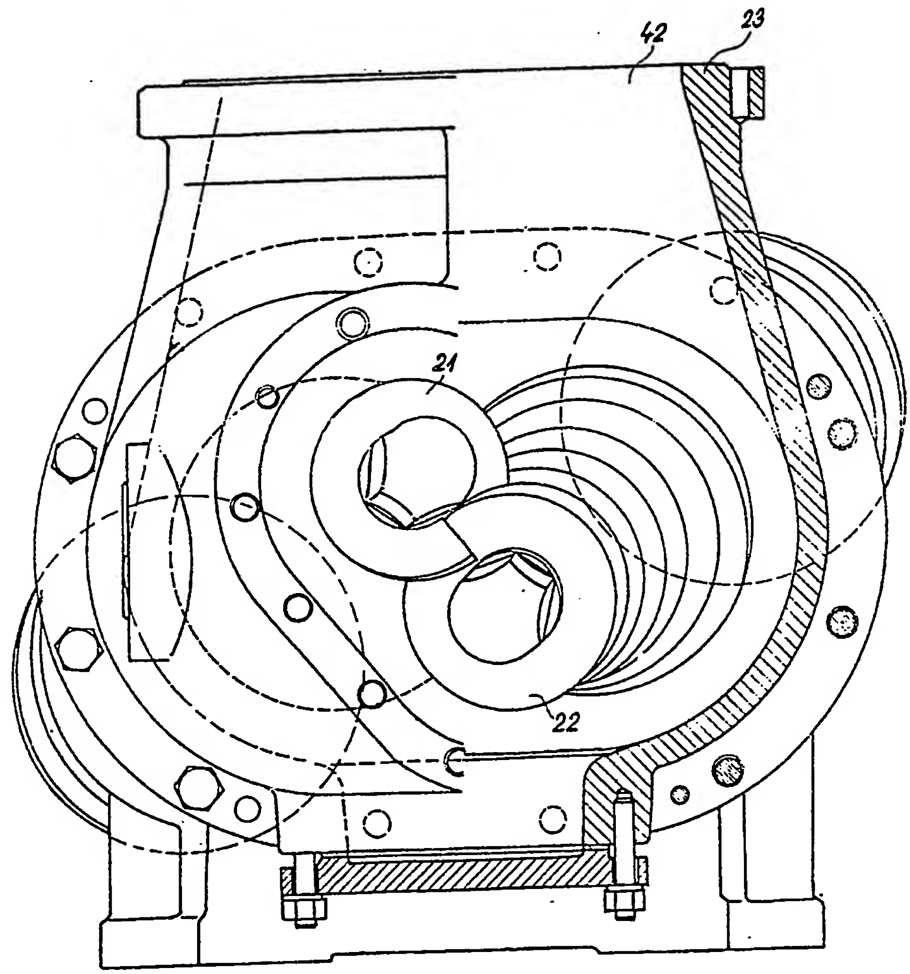


Fig. 2



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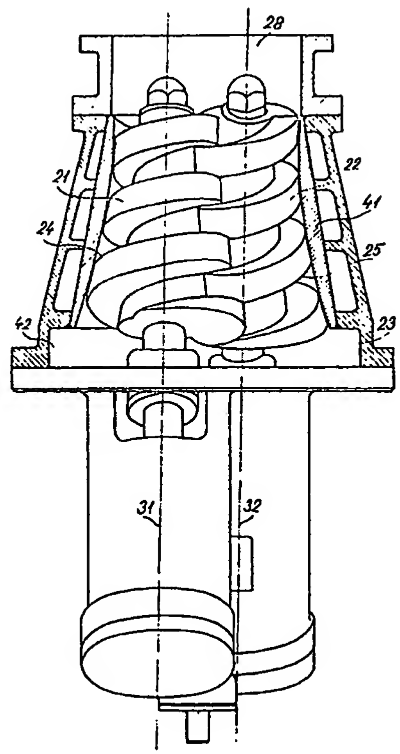

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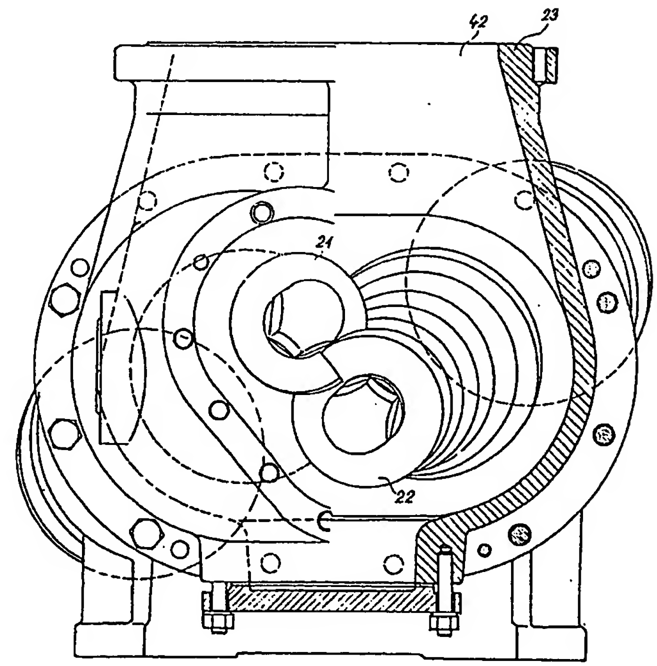

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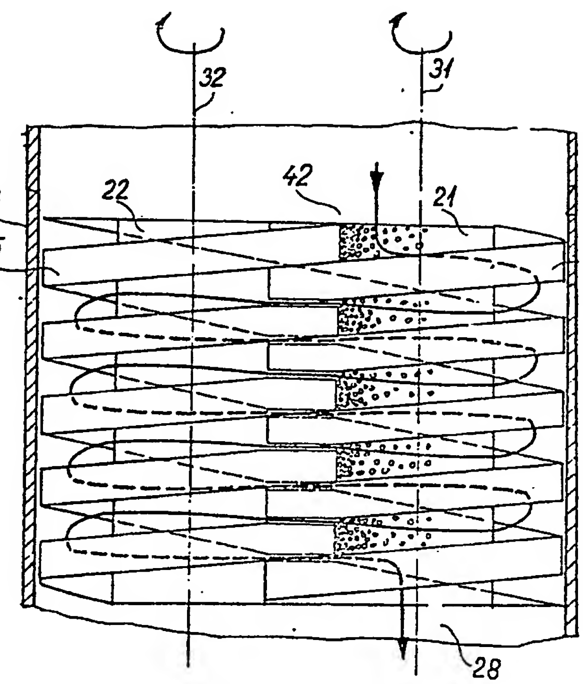

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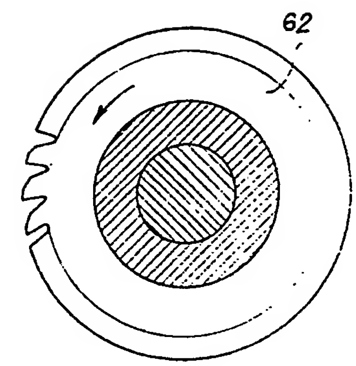

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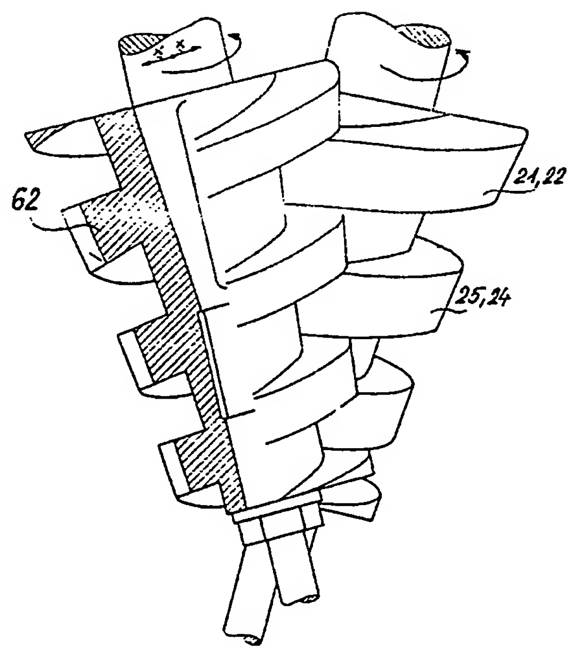

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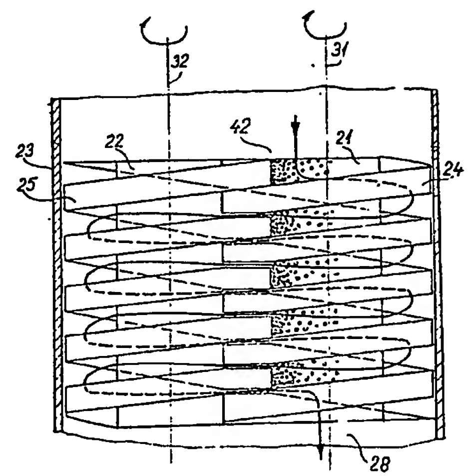

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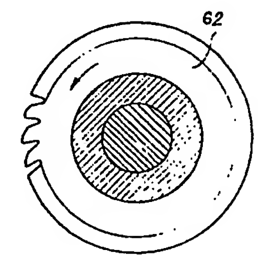

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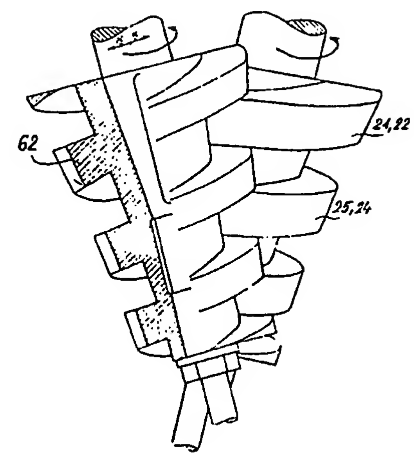

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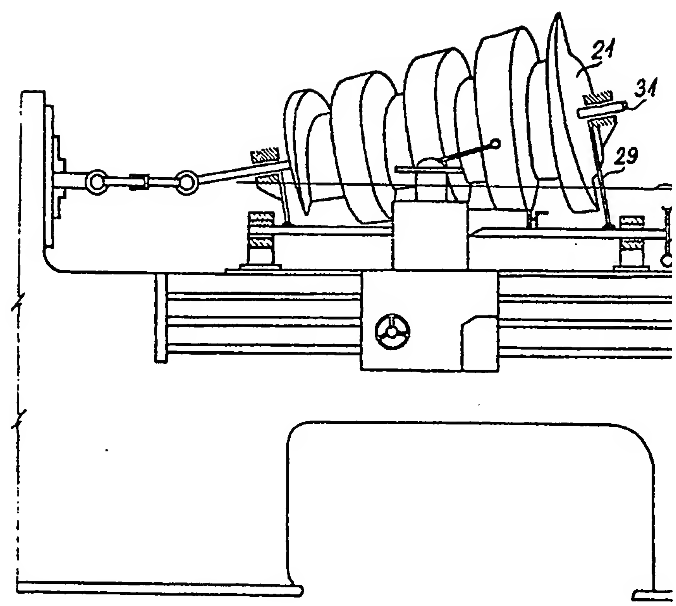

Fig. 7

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Sheets 6 & 7

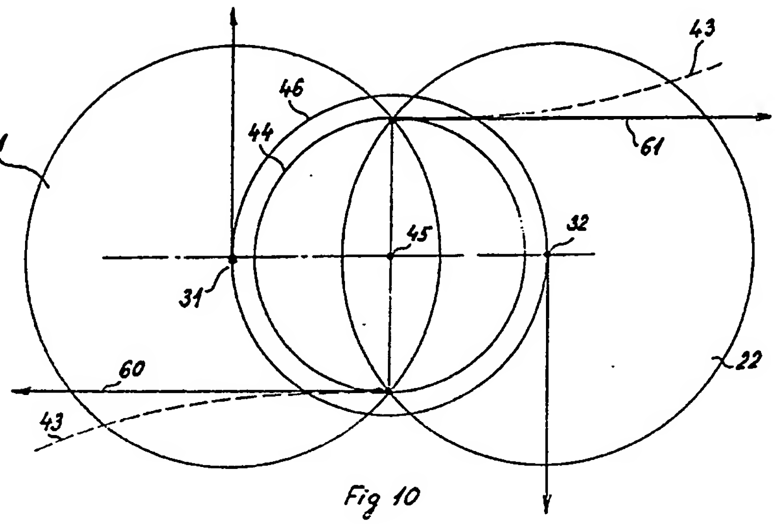


Fig 10

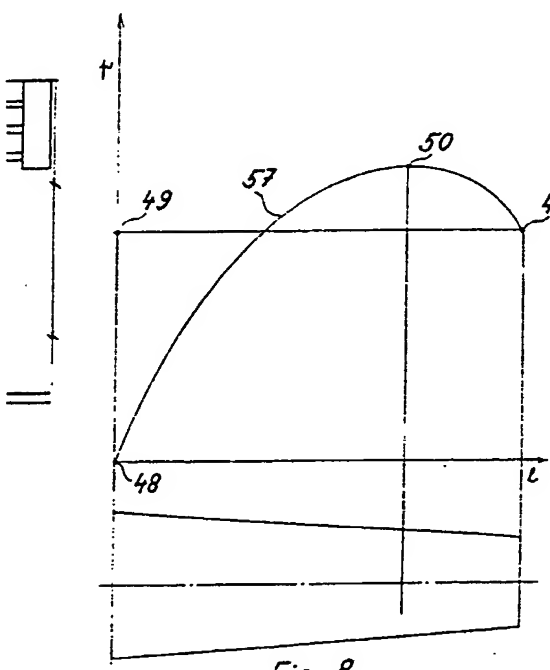


Fig. 8

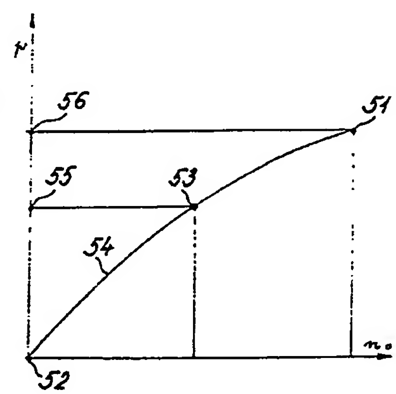
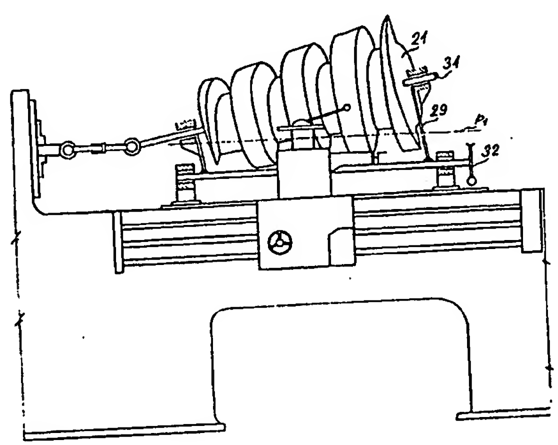


Fig 9



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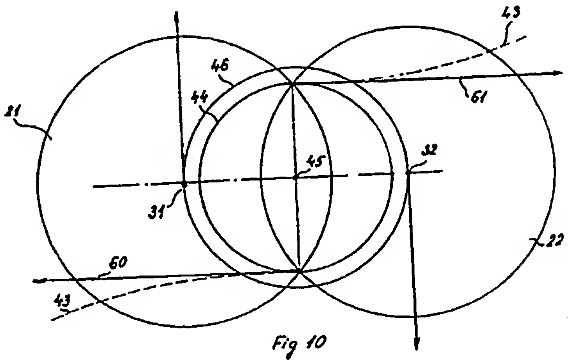

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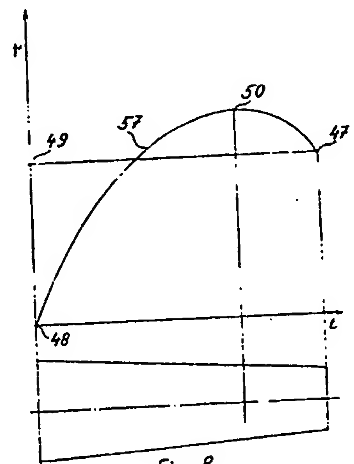

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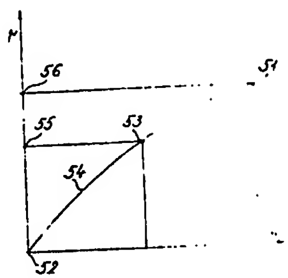

Fig 9